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Fourteenth day of October 2003

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SYSTEM AND METHOD(S) OF BLENDED MINE PLANNING, DESIGN AND PROCESSING

FIELD OF INVENTION

The present invention relates to the field of extracting resource(s) from a particular location. In particular, the present invention relates to the planning, design and processes related to a mine location in a manner based on enhancing the extraction of material considered of value, relative to the effort and / or time in extracting that material. In one form, the present invention relates to mining, mine planning and design which enhances blending of material and / or resource(s) extracted.

BACKGROUND ART

In the mining industry, once material of value, such as ore situated below the surface of the ground, has been discovered, there exists a need to extract that material from the ground.

In the past, one more traditional method has been to use a relatively large open cut mining technique, whereby a great volume of waste material is removed from the mine site in order for the miners to reach the material considered of value. For example, referring to Figure 1, the mine 101 is shown with its valuable material 102 situated at a distance below the ground surface 103. In the past, most of the (waste) material 104 had to be removed so that the valuable material 102 could be exposed and extracted from the mine 101. In the past, this waste material was removed in a series of progressive layers 105, which are ever diminishing in area, until the valuable material 102 was exposed for extraction. This is not considered to be an efficient mining process, as a great deal of waste material must be removed, stored and returned at a later time to the mine site 101, in order to extract the valuable material 102. It is desirable to reduce the volume of waste material that must be removed prior to extracting the valuable material.

The open cut method exemplified in Figure 1 is viewed as particularly inefficient where the valuable resource is located to one side of the pit 105 of a desirable mine site 101. For example, Figure 2 illustrates such a situation. The valuable material 102 is located to one side of the pit 105. In such a situation, it is not considered efficient to remove the waste material 104 from region 206, that is

where the waste material is not located relatively close to the valuable material 102, but it is considered desirable to remove the waste material 104 from region 207, that is where it is located nearer to the valuable material 102. This then brings other considerations to the fore. For example, it would be desirable to determine the boundary between regions 206 and 207, so that not too much undesirable waste material is removed (region 206), yet enough is removed to ensure safety factors are considered, such as cave-ins, etc. This then leads to a further consideration of the need to design a 'pit' 105 with a relatively optimal design having consideration for the location of the valuable material, relative to the waste material and other issues, such as safety factors.

This further consideration has led to an analysis of pit design, and a technique of removing waste material and valuable material called 'pushbacks'. This technique is illustrated in Figure 3. Basically, the pit 105 is designed to an extent that the waste material 104 to be removed is minimised, but still enabling extraction of the valuable material 102. The technique uses 'blocks' 308 which represent smaller volumes of material. The area proximate the valuable material is divided into a number of blocks 308. It is then a matter of determining which blocks need to be removed in order to enable access to the valuable material 102. This determination of 'blocks 308', then gives rise to the design or extent of the pit 105.

Figure 3 represents the mine as a two dimensional area, however, it should be appreciated that the mine is a three dimensional area. Thus the blocks 308 to be removed are determined in phases, and cones, which represent more accurately a three dimensional 'volume' which volume will ultimately form the pit 105.

Further consideration can be given to the prior art situation illustrated in Figure 3. Consideration should be given to the scheduling of the removal of blocks. In effect, what is the best order of block removal, when other business aspects such as time/value and discounted cash flows are taken into account? There is a need to find a relatively optimal order of block removal which gives a relatively maximum value for a relatively minimum effort/time.

Attempts have been made in the past to find this 'optimum' block order by determining which block(s) 308 should be removed relative to a 'violation free'

order. Turning to the illustration in Figure 4, a pit 105 is shown with valuable material 102. For the purposes of discussion, if it was desirable to remove block 414, then there is considered to be a 'violation' if we determined a schedule of block removal which started by removing block 414 or blocks 414, 412 & 413 before blocks 409, 410 and 411 were removed. In other words, a violation free schedule would seek to remove other blocks 409, 410, 411, 412 and 413 before block 414. (It is important to note that the block number does not necessarily indicate a preferential order of block removal).

It can also be seen that this block scheduling can be extended to the entire pit 105 in order to remove the waste material 104 and the valuable material 102. With this violation free order schedule in mind, prior art attempts have been made. Figure 5 illustrates one such attempt. Taking the blocks of Figure 4, the blocks are numbered and sorted according to a 'mineable block order' having regard to practical mining techniques and other mine factors, such as safety etc and is illustrated by table 515. The blocks in table 515 are then sorted 516 with regard to Net Present Value (NPV) and is based on push back design via Life-of-mine NPV sequencing, taking into account obtaining the most value block from the ground at the earliest time. To illustrate the NPV sorting, and turning again to Figure 4, there is a question as which of blocks 409, 410 or 411 should be removed first. All three blocks can be removed from the point of view of the ability to mine them, but it may, for example, be more economic to remove block 410, before block 409. Removing blocks 409, 410 or 411 does not lead to 'violations' thus consideration can be given to the order of block removal which is more economic.

NPV sorting is conducted in a manner which does not lead to violations of the 'violation free order', and provides a table 517 listing an 'executable block order'. In other words, this prior art technique leads to a listing of blocks, in an order which determines their removal having regard to the ability to mine them, and the economic return for doing so.

Nonetheless, the foregoing description and prior art techniques, are considered to ignore a number of key problems encountered in a typical mine implementation. An ore body in the ground is typically modeled as a three-dimensional grid of blocks. Each of these blocks has attributes, such as the

tonnage of rock and ore contained in the block. Given a three-dimensional block model of an ore body, the mine planner determines an extraction schedule (an extraction ordering of the blocks). In practice, an extraction must satisfy a number of constraints. For example, wall slopes must be maintained below a defined value to avoid pit walls collapsing and the rates of both removal of earth from the pit (mining rate) and ore processing (processing rate) must not exceed given limits. The wall slope constraints are usually taken into account using precedence relations between blocks. The removal of a given block requires the earlier removal of several blocks above it; that is removal of these several blocks must precede removal of the given block.

Typically, the blocks of highest value lie near the bottom of the ore body, far underneath the ground. A cash flow stream is generated when these blocks are excavated and the ore within them is sold. Because one can earn interest on cash received earlier, the value of a block increases if it is excavated earlier, and decreases (or is discounted) if it is excavated later. This concept of discounting is central to the notion of net present value (NPV). Thus the mine planner seeks an extraction schedule that maximizes the net present value of the ore body. The net present value forms the objective function of this optimization problem.

Calculating the NPV of an extraction schedule is far from easy. In current approaches, each block is simply ascribed a value in dollars, but in many cases, this value may be only a very crude approximation, and subject to change. For commodities such as copper, the planner needs to know the metal content of the block, the selling price at all future times within the planning horizon, the mining/processing costs, and some other factors. This is a difficult and problematic in itself.

However, for blended products such as coal or iron ore, the problem is considered even more difficult. This follows from the fact that the values of individual blocks are not known until those blocks have been blended with other blocks to form a saleable product. An individual block may be of sufficiently low quality to be considered worthless or waste material in isolation. A block having a relatively average quality may attract a certain price, given the price set for the material is based on a minimum quality level. Thus when a block having a

relatively higher quality is extracted, this block will receive only the same value as the average quality block because the value is based on a minimum quality level. For this reason, the low quality block, when blended with the high quality block, result in a volume of ore at or above the minimum quality level and thus the two ore blocks may be both sold. This 'blended' price is significantly more than the low quality and high quality blocks would be worth in isolation. This enables more revenues to be achieved from the extraction of resource(s). Blending is also particularly valuable for smoothing the grade of ore blocks sold when the grade of ore blocks coming out of the pit is relatively erratic. Thus, the value of a block is unknown until it is part of a blended extraction schedule.

In addition to the factors described above, the sheer dimensions of the problem confronting a mine planner, with hundreds of thousands of blocks and up to a 30-year time horizon make it very difficult to find an extraction schedule that maximizes the total NPV of the mine very difficult.

It is considered that some prior art approaches approximate heavily, by aggregating either blocks or time periods, are considered to solve the problem in a piecemeal fashion, or relying on heuristic methods. The treatment of blending is considered to be done by relatively crude approximations. The prior art assumes a value and then seeks to optimise a schedule. But if the assumed value is not correct, especially over a relatively long period of time, then the schedule could not be considered optimal.

Other prior art approaches, in the form of some commercial software, enable post-schedule blend optimization to be performed. The software determines an extraction schedule based on estimated "in pit" valuation of each block, and then a blending schedule is developed based on the extraction sequence given. This is considered not very accurate in a commercial situation as the in-pit valuations are estimates, and thus may be far from reflecting a true resulting blended value. Furthermore, the blending schedule itself is often determined by heuristic methods, which may yield far from optimal solutions.

The Whittle Four-X Analyser (by Whittle Pty Ltd) attempts to integrate scheduling and blending by iteratively updating the schedule and blend using a hill-climbing heuristic, although the blending optimization is still local in time. MineMAX (by MineMax Pty Ltd) and ECSI Minex Maximiser (by ECS International

Pty Ltd) have partially integrated scheduling and blending. However, the blocks are valued "in ground" in isolation, not as part of a blend, and the blending optimization is performed locally in time due to problem size limitations.

Given the importance of blending, it is essential to consider these factors as an integral part of schedule development. Improvements in the accuracy of the mine model and analysis techniques will clearly lead to increased mine value, which can lead to increased revenues in the order of many millions of dollars over the life of a relatively large mine.

Given the commercial significance of a mine and the relatively large scale nature of a mine, there is a need to improve mine design and / or the method(s) used to design a mine.

Another object of the present invention is to alleviate at least one disadvantage of the prior art.

Any discussion of documents, devices, acts or knowledge in this specification is included to explain the context of the invention. It should not be taken as an admission that any of the material forms a part of the prior art base or the common general knowledge in the relevant art in Australia or elsewhere on or before the priority date of the disclosure and claims herein.

SUMMARY OF INVENTION

The present invention provides, in one aspect, a method of determining the removal of material(s) from a location, the method including the steps of calculating revenue, and determining a schedule with regard to grade constraints.

The present invention provides in another aspect, a method of determining the removal of material(s) from a location, the method including the steps of calculating revenue, and determining a schedule with regard to impurity constraints.

Preferably, the determination of the schedule is made with regard to both grade and impurity.

The present invention provides, in still another aspect, the determination of a schedule according to the expression 1 as herein disclosed.

The present invention provides in a further aspect, the determination of a revenue associated with a schedule allowing for whole and / or fractional block/clump and / or panel(s).

Other aspects and preferred aspects are disclosed in the specification and / or defined in the appended claims.

In essence, in one aspect, the present invention, seeks to blend material mined in order to provide saleable material, preferably of a greater volume than material of value extracted directly from a mine. In other words, the present invention, based on knowledge of the grade and impurity of each block/clump/panel, includes such information into the schedule iteration. The schedule, in accordance with the present invention, is therefore calculated taking into account grade and impurity over a period of time, for example, 1 year. These factors may also be utilised in integer programs.

Another aspect of the present invention serves to provide a revenue determination as whole or partial blocks, clumps and / or panels. This information can be used in determining schedule(s).

Advantageously, it has been found that the present invention provides the ability to relatively maximise the volume of material for which revenues can be generated from a mining operation.

The present invention may be used, for example, by mine planners to design open cut mines, but the present invention should not be limited to only such an application.

Throughout the specification:

1. a 'collection' is a term for a group of objects,
2. a 'cluster' is a collection of ore blocks or blocks of otherwise desirable material that are relatively close to one another in terms of space and / or other attributes,
3. a 'clump' is formed from a cluster by first producing a substantially minimal inverted cone extending from the cluster to the surface of the pit by propagating all blocks in the cluster upwards using the arcs that describe the minimal slope constraints. Each cluster will have its own minimal inverted cone. These minimal inverted cones are then intersect with one another and the intersections form clumps,
4. an 'aggregation' is a term, although mostly applied to collections of blocks that are spatially connected (no "holes" in them). For example, a clump

may be an aggregation, or may be "Super blocks" that are larger cubes made by joining together smaller cubes or blocks, and

5. a 'panel' is a number of blocks in a layer (bench) within a pushback.

DESCRIPTION OF DRAWINGS

Further disclosure, objects, advantages and aspects of the present application may be better understood by those skilled in the relevant art by reference to the following description of preferred embodiments taken in conjunction with the accompanying drawings, in which:

Figures 1 to 5 illustrate prior art mining techniques, and

Figure 6 illustrates schematically an application of the present invention.

DETAILED DESCRIPTION

In a preferred embodiment of the present invention, it is assumed that all blocks in this block model are of equal volume. The present invention has equal applicability to block(s), clump(s), panel(s) and / or any amount/volume of material. It is assumed that blended products are created, the sale price of which are dependent on the volume of product that meets certain specifications of grade and impurities.

For example, with reference to Figure 6, there is shown illustratively the outcome of the blending of the present invention. In blending, a block/clump/panel 1 having relatively little, no, or waste value may be blended (that is mixed, at least in part) with a block 2 having a value $x of ore or material. In essence, the block 2, although it has a value of $x, will only achieve a sale price of $y, that is the sale price agreed with the customer. This is the case because, as is often the case in the sale of mined materials, revenue generated by the sale of the material is usually based on a customer agreeing to pay a fixed price for material/blocks/clumps. The material sold must meet a certain minimum requirement, and is not usually based in the actual amount of ore or valuable material contained in each block/clump/panel. Thus, even though block 2 has a value $x, the customer will only pay an agreed price $y, for example. Thus, in the example illustrated, the mining of blocks 1 and 2 will only generate revenue of $y by the sale of block 2 and block 1 will be considered waste. Costs will be incurred also in disposing of the waste block 1.

In accordance with the present invention, however, block 1 and block 2 are blended in a manner which results in two blocks, each having a saleable revenue of \$y. For the sake of illustration, the blending of these two blocks has resulted in two blocks, each of which at least meet the minimum saleable revenue of \$y. The outcome of the blend, in the example illustrated is that two blocks/clumps/panels are obtained, each with a revenue value of \$y, and thus the overall revenue has been raised to 2 x \$y.

Calculation of Revenue

The embodiment of the present invention may be expressed as a formulation. In this regard, the mixed integer linear program to be solved seeks: relatively maximal NPV, as a function of (i) amount of blocks contributed toward each product, discounted appropriately, and taking into account selling revenue and blending/processing costs, (ii) mining costs, and (iii) costs of placing material on a waste dump.

In considering the present invention, previous techniques have assumed a value for each block/clump/panel. In a blended volume of material, the value cannot be assumed over a period of time. Thus, in accordance with the present invention, revenue which represents a consideration in a mine design, may be expressed as:

$$\text{(Revenue) } R = \sum(A \,.\, D \,.\, F) - \sum(C \,.\, D \,.\, E) - \sum(W \,.\, D \,.\, (E - F)) \qquad \text{expression 1}$$

where:

A denotes the revenue received from a unit volume of product

C is mining cost per block, clump and / or panel

D represents a variable discount for future values of $v_i(\omega)$ in that $v_i(\omega)$ denotes the 'value' (in today's dollars) of a block/clump/panel having a identification number i,

E is 1 if the block/clump/panel is excavated and 0 otherwise,

F is a fraction of a block considered to be ore, and

W is cost of waste per block/clump/panel.

To utilise the above expression, it may be input to a linear mixed integer program solver. In one embodiment, existing linear mixed integer programming solvers may be used to solve a program of the form:

max	Revenue	....expression 2
subject to	precedence constraints	
	production rate constraints	
	grade constraints	
	impurity constraints	

Constraints to be met are (i) arc precedence constraints, (ii) grade constraints, preferably on an annual basis for each product, (iii) impurity constraints, preferably on an annual basis for each product, and (iv) production constraints such as mining rate constraints, processing rate constraints and marketing rate constraints.

The integer program selects in a relatively NPV-optimal way: (i) when to excavate and process/blend blocks/clumps, (ii) what blocks/clumps to blend together to achieve grade and impurity, and (iii) how to allocate blocks/clumps (or portions of blocks) to make each product (or to assign to waste).

A relatively "ultimate pit" for a blended mine

In a further aspect of the present invention, the problem of determining a relatively ultimate pit design is addressed. In other words, determining a relatively large pit (relatively large undiscounted value) that can conceivably encompass a schedule that will meet blend constraints.

This aspect of invention applies the above expression 2 to a single time period (in essence, everything is considered to happen instantaneously with no discounting). Essentially, everything occurs in one period. In this aspect, there are no production rate constraints, but the other constraints are retained. Furthermore, D=1 in expression 1.

Allowing for fractions of blocks/clumps/panels in periods

There is a further need to allow for fractions of blocks/clumps/panels. This results because in a given time period, it is not always possible to extract and / or process a whole block/clump/panel. Thus only a fraction may be excavated and / or processed.

It has been advantageously determined that in order to allow for fractions of blocks/clumps/panels, in the above expression(s) 'E' can be replaced by a variable 'G',

where:

the prescribed variable G represents a portion of a block/clump/panel, and in where $0 \leq G \leq 1$ and $G \leq E$.

While this invention has been described in connection with specific embodiments thereof, it will be understood that it is capable of further modification(s). This application is intended to cover any variations uses or adaptations of the invention following in general, the principles of the invention and including such departures from the present disclosure as come within known or customary practice within the art to which the invention pertains and as may be applied to the essential features hereinbefore set forth.

As the present invention may be embodied in several forms without departing from the spirit of the essential characteristics of the invention, it should be understood that the above described embodiments are not to limit the present invention unless otherwise specified, but rather should be construed broadly within the spirit and scope of the invention as defined in the appended claims. Various modifications and equivalent arrangements are intended to be included within the spirit and scope of the invention and appended claims. Therefore, the specific embodiments are to be understood to be illustrative of the many ways in which the principles of the present invention may be practiced. In the following claims, means-plus-function clauses are intended to cover structures as performing the defined function and not only structural equivalents, but also equivalent structures. For example, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface to secure wooden parts together, in the environment of fastening wooden parts, a nail and a screw are equivalent structures.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of determining the removal of material(s) from a location, the method including the steps of:

calculating revenue, and

determining a schedule with regard to grade constraints.

2. A method of determining the removal of material(s) from a location, the method including the steps of:

calculating revenue, and

determining a schedule with regard to impurity constraints.

3. In combination, a method as claimed in claim 1 and 2.

4. A method of determining the removal of material(s) from a location for a mining operation, the method including the step of :

calculating a schedule, having regard to the expression:

(Revenue) $R = \sum(A \cdot D \cdot F) - \sum(C \cdot D \cdot E) - \sum(W \cdot D \cdot (E - F))$

where:

A denotes the revenue received from a unit volume of product

C is mining cost per block, clump and / or panel

D represents a variable discount for future values of $v_i(\omega)$, in that $v_i(\omega)$ denotes the 'value' (in today's dollars) of a block/clump/panel having a identification number i,

E is 1 if the block/clump/panel is excavated and 0 otherwise,

F is a fraction of a block considered to be ore, and

W is cost of waste.

5. A method as claimed in claim 4, wherein fraction of block/clump and or panel is calculated by expression:

(Revenue) $R = \sum(A \cdot D \cdot F) - \sum(C \cdot D \cdot G) - \sum(W \cdot D \cdot (G - F))$

where:

A denotes the revenue received from a unit volume of product

C is mining cost per block, clump and / or panel

D represents a variable discount for future values of $v_i(\omega)$, in that $v_i(\omega)$ denotes the 'value' (in today's dollars) of a block/clump/panel having a identification number i,

F is a fraction of a block considered to be ore,

G represents a portion of a block/clump/panel, and in where $0 \leq G \leq 1$ and $G \leq E$, and E is 1 if the block/clump/panel is excavated and 0 otherwise, and

W is cost of waste.

6. Apparatus adapted to determine the removal of material from a location, said apparatus including:

processor means adapted to operate in accordance with a predetermined instruction set,

said apparatus, in conjunction with said instruction set, being adapted to perform the method as claimed in any one of claims 1 to 5.

7. A block, clump and / or panel schedule established in accordance with the method as claimed in any one of claims 1 to 5.

8. A computer program product including:

A computer usable medium having computer readable program code and computer readable system code embodied on said medium for determining the removal of material from a location and operable within a data processing system, said computer program product including:

computer readable code within said computer usable medium for determining, at least in part, a schedule in accordance with claim 7.

9. A computer program product including:

A computer usable medium having computer readable program code and computer readable system code embodied on said medium for determining the removal of material from a location and operable within a data processing system, said computer program product including:

computer readable code within said computer usable medium for determining the removal of material from a location, at least in part, in accordance with the method as claimed in any one of claims 1 to 5.

DATED THIS 14th day of November 2002
BHP BILLITON INNOVATION PTY LTD

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Figure 1
(prior art)

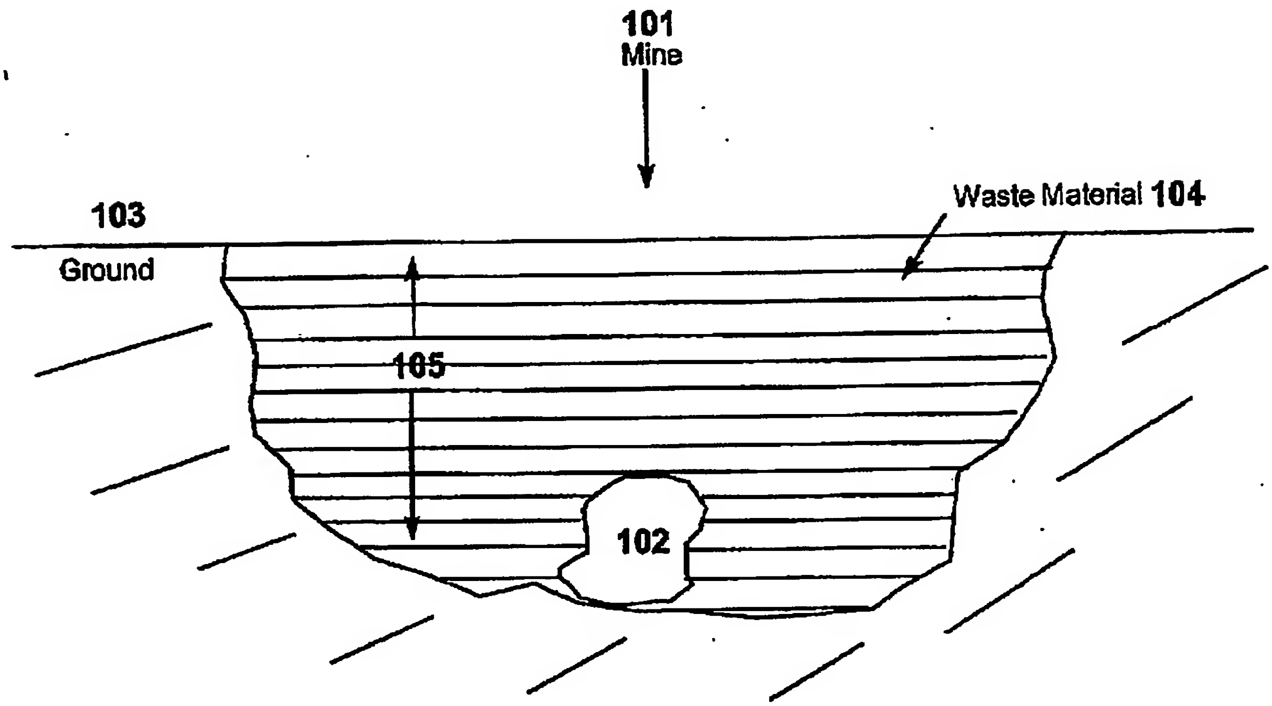


Figure 2
prior art

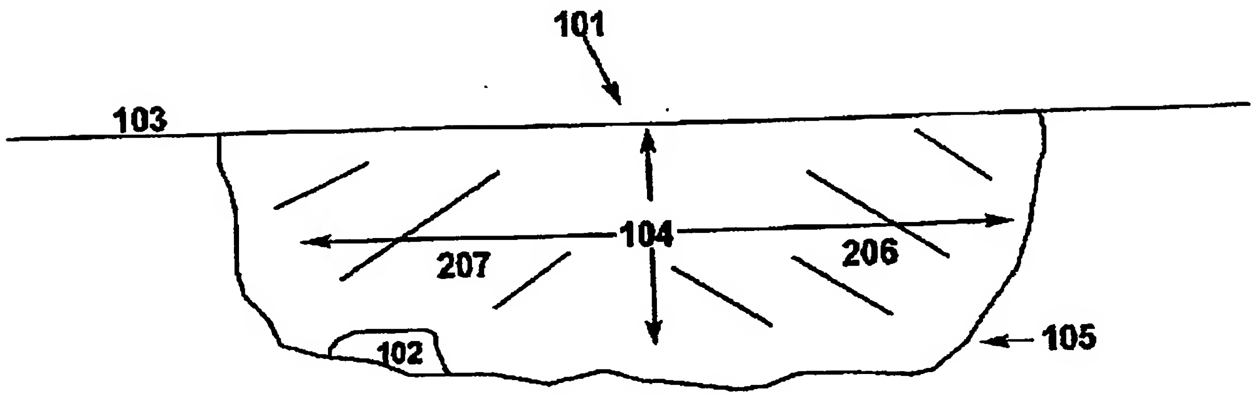
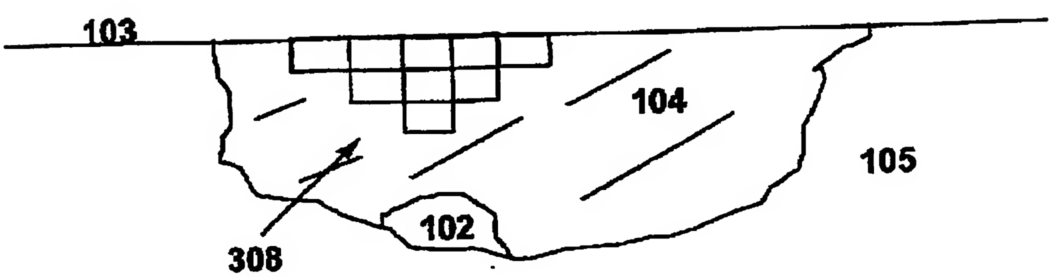


Figure 3
prior art



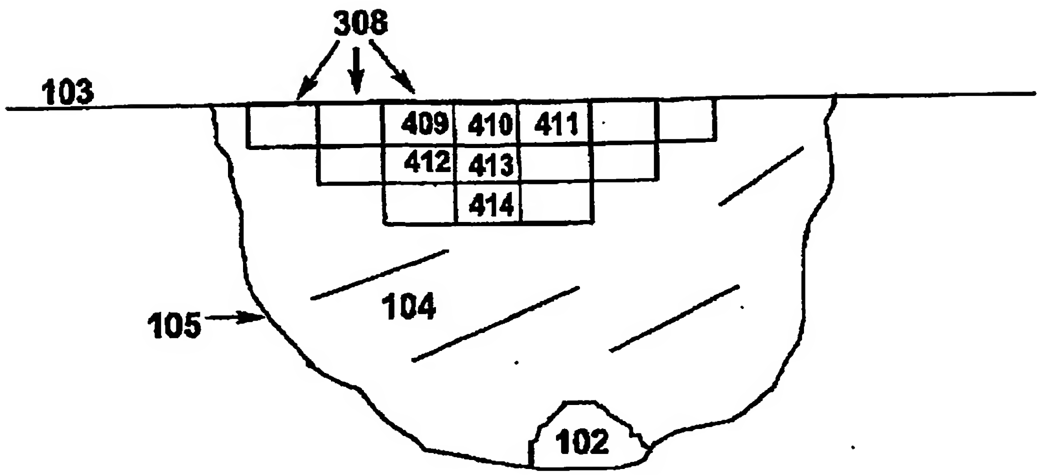


Figure 4
prior art

Figure 5
prior art

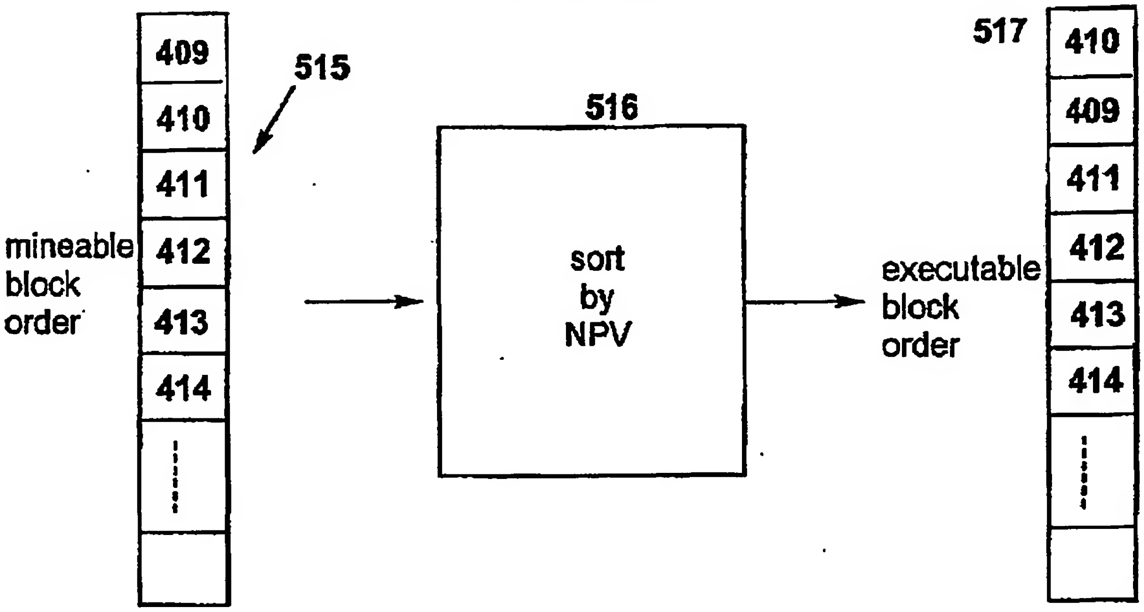


Figure 6